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# P3_4 A Linear Electromagnetic Mass Driver Powered Elevator

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**Abstract**

This paper applies the electromagnetic theory that forms the basis of the railgun mass driver to an elevator with comparable performance to those that are found in large buildings around the world. The current required to accelerate an inhabited elevator chamber was found to be $266kA$.

## Introduction

Currently, elevators are operated by suspending a lift chamber in a shaft by long steel cables. If the elevator is required to go up, a large motor pulls the chamber up the shaft, sometimes with additional help from a counterweight. This article investigates the feasibility of using electromagnetics to operate the elevator in a way similar to that of a railgun.

## Theory

A railgun is a mass driver that makes use of electromagnetism to accelerate a projectile. It comprises of a pair of conducting rails, connected by an armature through which a current flows to complete the circuit, as shown in figure 1.

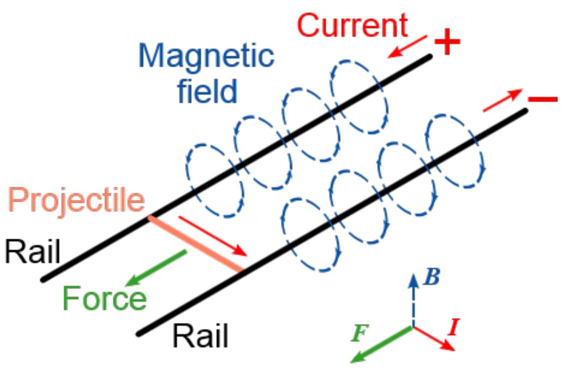


Fig. 1: Electromagnetics of a Railgun [1]

The Lorentz relation describes the force applied to the armature by the generation of the magnetic field by the flowing current,

$$\mathbf{F} = q(\mathbf{E} + \mathbf{v} \wedge \mathbf{B}), \tag{1}$$

where $\mathbf{F}$ is the resultant force acting on the particle of electric charge, $q$, with a velocity $\mathbf{v}$ due to an electric field, $\mathbf{E}$, and the magnetic field $\mathbf{B}$. A suitable form for this application is that of the force applied to a current carrying wire,

$$\mathbf{F} = I \int d\mathbf{l} \wedge \mathbf{B}, \tag{2}$$

where $d\mathbf{l}$ is an infinitesimal segment of wire.

The magnetic field generated by an electric current is described by the Biot-Savart law,

$$\mathbf{B} = \frac{\mu_0 I}{4\pi} \int_c \frac{d\mathbf{l} \wedge \hat{\mathbf{r}}}{|\mathbf{r}|^2}, \tag{3}$$

where $\mathbf{B}$ is the generated magnetic field at point $\mathbf{r}$ by the current $I$, $\mu_0$ is permeability of free space, and $d\mathbf{l}$ in this equation is a vector, the magnitude of which is the differential element of the wire in the direction of the current.

The magnetic field $\mathbf{B}(s)$ at a distance $s$ away from the wire can be found by applying the Biot-Savart law to the situation of a wire of infinite length with a current running through it;

$$\mathbf{B}(s) = \frac{\mu_0 I}{2\pi s}. \tag{4}$$

Equation (4) can be manipulated further by applying it to each rail of the railgun, and also by taking into account the fact that the rails have a finite non-zero radius, which is not accounted for in the infinite wire approximation. The result, shown in E. Chien [2], is,

$$\mathbf{B}(s) = \left( \frac{\mu_0 I}{4\pi(R+s)} + \frac{\mu_0 I}{4\pi(R+w-s)} \right), \tag{5}$$

where $w$ is the distance between the rails and $R$ is the radius of the rails themselves. Substituting the expression for the magnetic field (equation 5) into the differential form of Lorentz Force on a wire (equation 2) and integrating between $w$ and 0 gives,

$$\mathbf{F} = \frac{\mu_0 I^2}{2\pi} ln \left( \frac{R+w}{R} \right) \hat{\mathbf{z}}. \tag{6}$$

Equation (6) relates the force applied to the armature, in this case the elevator chamber, with the current that is applied through the conducting rails and the dimensions of the overall system.

To demonstrate the feasibility of a railgun-type electromagnetic elevator, the current required to operate such a system under relatively normal operating conditions must be calculated. The overall force on the elevator chamber is the total of both the driving force and resistive forces. In this case, friction and air resistance are neglected leaving only the resistive force due to gravity,

$$\mathbf{F_T} = \mathbf{F_M} + \mathbf{F_G} = \frac{\mu_0 I^2}{2\pi} ln\left(\frac{R+w}{R}\right)\hat{\mathbf{z}} - M\mathbf{g}, \quad (7)$$

where $\mathbf{F_T}$ is the total force on the elevator chamber, $\mathbf{F_M}$ is the Lorentz Force on the elevator chamber, $\mathbf{F_G}$, $M$ is the total mass of the chamber and its occupants and $\mathbf{g}$ is the acceleration due to gravity. A more useful form of this equation is if it is rearranged in terms of the mass and acceleration, $\mathbf{a}$, of the lift chamber itself, where $\mathbf{F_T} = M\mathbf{a}$ and solved for the current,

$$I = \left(\frac{2\pi M(a+g)}{\mu_0(ln(R+w) - ln(R))}\right)^{\frac{1}{2}}. \quad (8)$$

**Dicussion**

The required acceleration of the elevator has been set to that of the Taipei 101 elevator system, which is on average $1.7ms^{-2}$ [3], or approximately $0.18g$. Other assumed values used to demonstrate the feasibility of the railgun-type electromagnetic elevator are the mass of the elevator and the mass of the people within. These are $1500kg$ and $700kg$ respectively (based upon 10 people of 70kg mass). The final assumptions made are about the dimensions of the lift. The lift chamber is a $w = 2.5m$ cube and the the rails upon which the force of the lifts ascent is distributed have a radius $R = 0.5m$.

Using these values, the current required to apply enough force on the lift chamber to accelerate up the shaft at the stated value is $266kA$. One thing to note about this current is that it is sustained for the duration of the acceleration period. During periods when the lift is either decelerating or stationary, there is also a requirement for a varying current to counteract the force due to gravity (or it will fall down the shaft).

**Conclusion**

The required current value may seem high, but the Naval railguns developed for the US Navy by BAE Systems use on the order of 1 million amps [4] to deliver the projectile of its weapon system. However, this is almost instantaneous and does not need to be sustained. It is achieved by using a bank of capacitors, something which may not be suitable for a large commercial building. Further studies could assess the implications of strong magnetic fields on both the surroundings and the occupants of the elevator. No further thought has been given to the engineering or financial considerations of a railgun-type electromagnetic elevator system. This type of technology could be used in the operation of elevator-type horizontal transportation systems, allowing convenient access and movement around large buildings. It has also been applied in the past as a theoretical means of accessing space.

**References**

[1] http://upload.wikimedia.org/wikipedia/commons/9/9a/Railgun-1.svg accessed on 16/10/2013.

[2] E. Chien, Dartmouth Undergraduate Journal of Science, (2007).

[3] http://www.forbes.com/2007/10/01/elevators-economics-construction-biz-logistics-cx_rm_tvr_1001elevators.html accessed on 16/10/2013.

[4] http://www.naval-technology.com/features/featureus-navy-electromagnetic-railgun-programme accessed on 16/10/2013/.